SLR Technology Development

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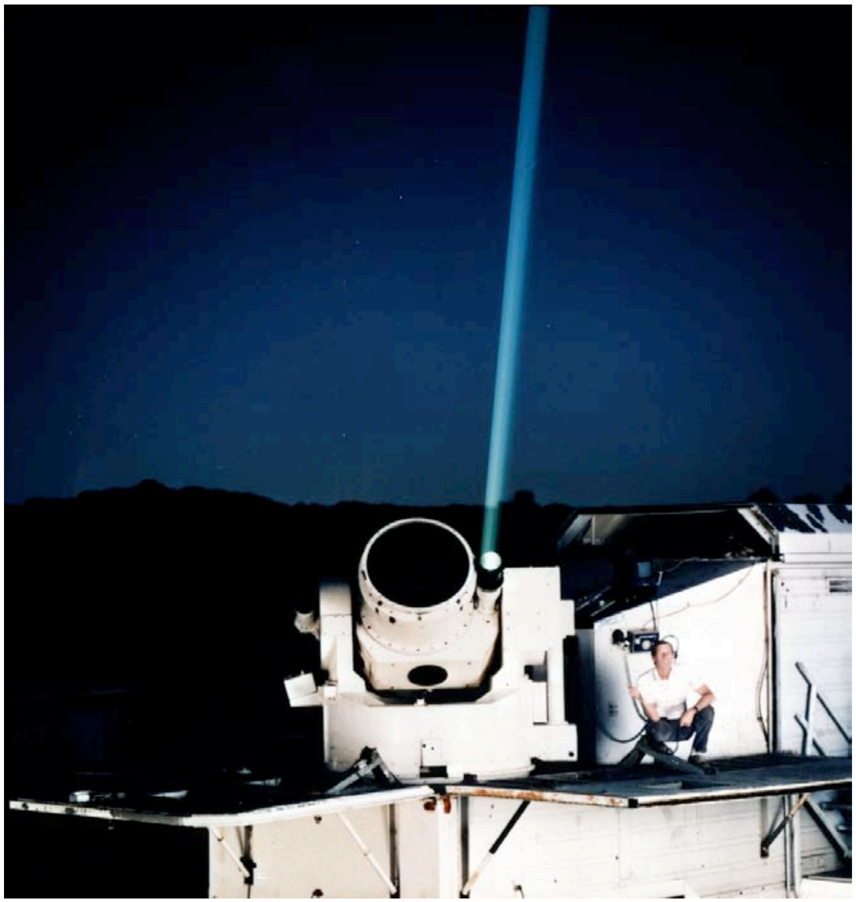
Presentation Outline

- The current Goddard SLR network
- Current SLR challenges
- End of SLR Network upgrade path?
- Lessons learned in 25 years SLR
- SLR2000: Future of Satellite Laser Ranging
- Enabling Technologies/Innovative hardware
- SLR2000 Key instrumentation
- Overview/Objective/Requirements
- Tracking Specifications Table
- Gimbal/Telescope/System Block Diagram
- Risks, Issues, and Future Plans

The Current NASA SLR Network

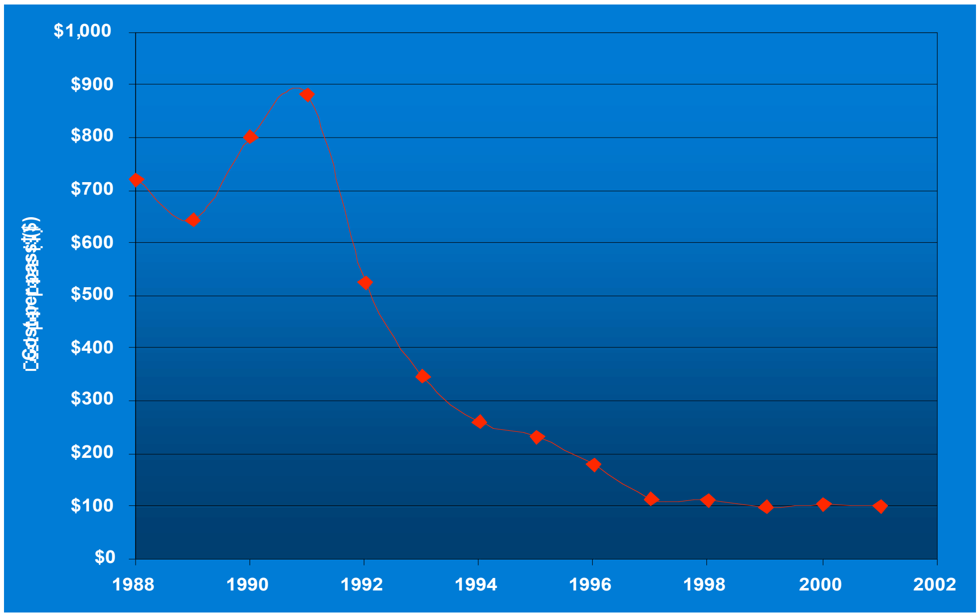


- Late 70’s technology
- Multiple subsystem upgrades
- Single man operation
- Costly to operate/maintain
- Spare parts unobtainable
- More tracking demands
- Upgrade path exhausted
- Operator health/safety hazards still exist

New instrumentation, enabling technologies, and more computing power hint of the future

NASA SLR Current Challenges

SLR Cost Per Pass Down



Current NASA Systems have improved data quality and quantity over last 10 years.

- Decreased operating costs through system improvements, automation, and crew cross-training
- More satellite missions supported
- Sub-centimeter performance with subsystem upgrades

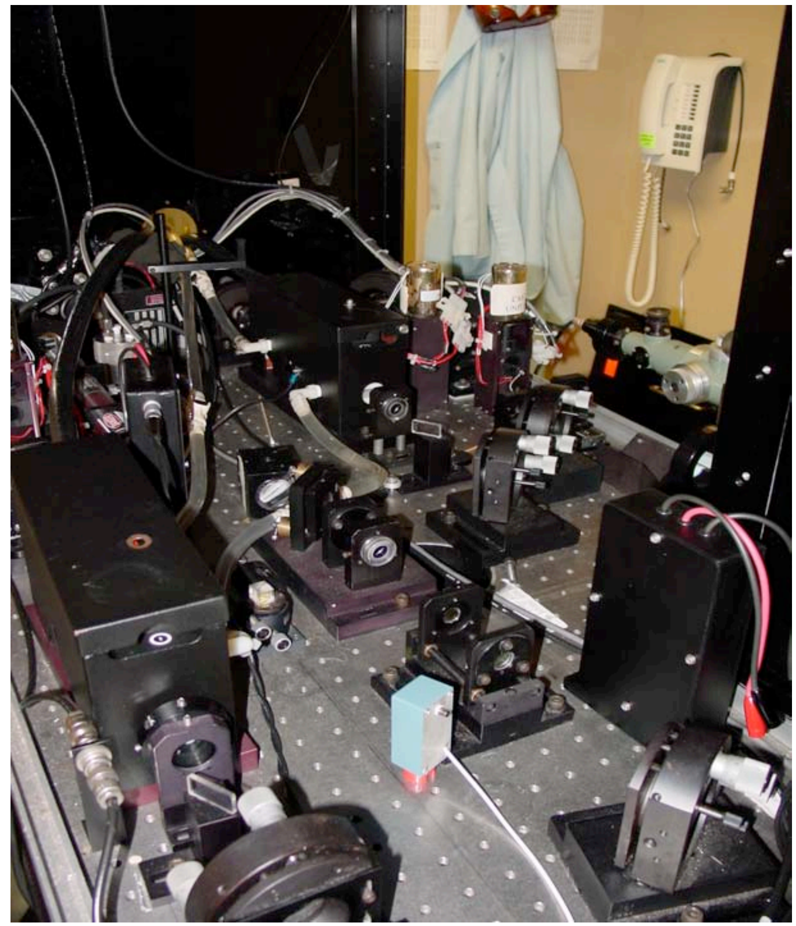
Performance limits have been reached with existing systems

End of SLR Upgrade Path?

- Network deployed in late 70’s
- Q-switched lasers replaced early 80’s with mode-locked lasers
- 1 to 5 Hz laser upgrade
- TIU’s replaces early 80’s
- MCP PMT introduced mid-80’s
- Timing electronics late 80’s
- Multiple CPU upgrades
- Radar installed in the 90’s
- “MAXed” out in data quality and quantity

SLR Network Hazards Still Exist

- Electrical: Lethal HV capacitor banks for flash lamp pumping of laser rods
- Chemical: Flowing dye cell for Q-switching laser, gloves required (carcinogen)
- Fumes: Vented hood and respirator required
- Ocular: 100mJoules/pulse, safety goggles, radar or safety observer required



What have we learned in 25 years of SLR?

- Data quality improves with shorter laser pulses and higher receiver bandwidths
- SLR instrumentation timing error sources need to be identified and quantified
- 24/7 operation becomes routine with adequate satellite predicts, appropriate gating and receiver FOV, BPF, etc.
- Upgrade paths of new technologies and instrumentation should be considered
- More real time computing power is always an advantage
- Use photons efficiently: i.e. Single photon range measurement can be as accurately as multiphoton detection

SLR2000: The Future of SLR

- Fully automated, no operator
- Centimeter ranging accuracy
- Tracks satellites to 20,000 km altitude, 24/7 operation
- No ocular, chemical, or electrical hazards
- Automated satellite scheduling
- Increased reliability, MTBF >4 months
- Small, compact, self-monitoring, low maintenance
- Data processing/delivery via internet
- Lower replication/operating costs

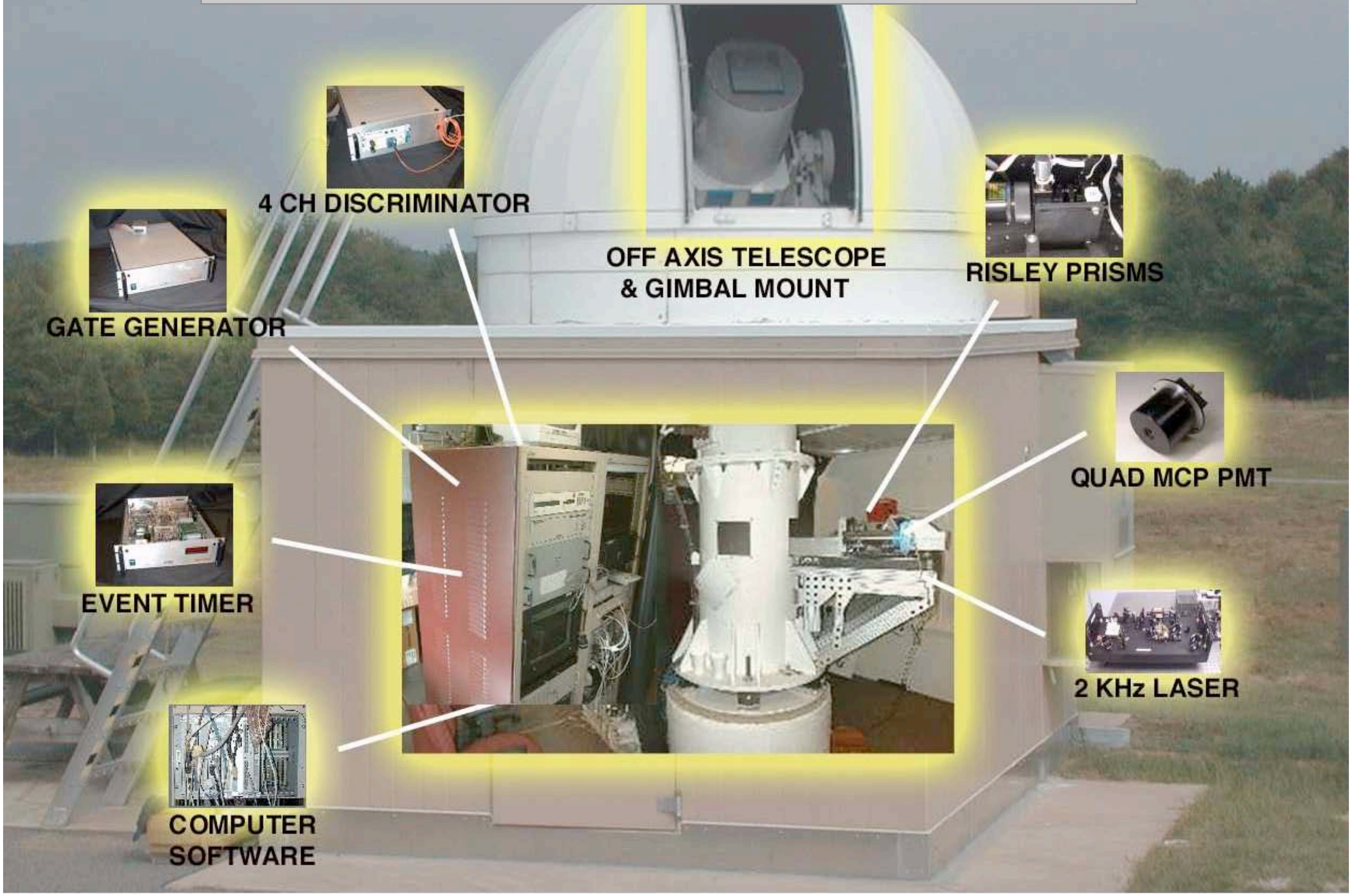
Enabling Technologies

- Quad Microchannel plate photomultiplier tube
- Nd:YAG microchip laser
- High speed Event Timers and Range Gate Generator
- More real time computing power
- Signal algorithm development
- Smart weather instrumentation
- Internet data flow

Innovative Hardware Developed for SLR2000

- New quadrant microchannel plate PMT
- Passive 2 kHz transmit/receive switch
- Full aperture telescope use (eyesafe)
- Risley prism point ahead of transmitted beam
- All sky thermal IR camera
- 2 kHz Event Timer/Range Gate Generator
- Signal recognition algorithms
- Closed loop tracking with quadrant timing detector

SLR2000 Key Instrumentation



MOBLAS/SLR2000 Comparison

	MOBLAS	**SLR2000**
Transmitted Energy	100 mJoules	130 uJoules
Repetition Rate	5 Hz	2000 Hz
Average Power	.5 Watts	.26 Watts
Accuracy	~1 cm RMS	~1 cm RMS
Average pe level	10-1000 pe’s	<1 pe
Returns/second	5	few to 1000

SLR2000 Overview

- Laser: Diode pumped microchip ND:YAG (2 kHz operation)
- Receiver: Single photon detection quadrant MCP PMT
- Superior optics: Minimal obscuration, passive T/R switch
- Tracking mount: Elevation over azimuth gimbal
- TOF measurement: Multi-channel event timer
- Eyesafe autonomous operation: No radar needed
- Weather station: Site sky conditions, P/T/RH, wind, visibility
- Pseudo operator: Intelligent task selection
- Feedback: Central facility monitors

SLR2000 Tracking Specifications

- **Laser: Nd:YAG** — **Diode pumped Osc/Amp**
  - **Fire rate:** — **2 kHz**
  - **Pulse Energy:** — **135 uJoules/pulse at exit aperture**
  - **Beamwidth:** — **Variable: 10 to 40 arcseconds (FWHM)**
  - **Point ahead:** — **Risley prism pair (0-11 arcseconds)**
- **Detector:** — **Photek quadrant MCP PMT**
  - **Gain:** — **3.E+6**
  - **QE:** — **13% at 532 nm**
  - **Image area:** — **6mm diameter quadrant centered**
- **Receiver:** — **4 independent channels**
  - **Field of View:** — **10 to 40 arcseconds**
  - **Discriminator:** — **Phillips Scientific 708**
  - **TIU:** — **HTSI 1.5 psec resolution Event Timer**
- **T/R switch:** — **Passive (Polarization insensitive)**
- **Tracking mount:** — **Xybion Corp Ax/El gimbal**
- **Telescope:** — **Orbital Science Corp (OSC) 40 cm off-axis**
- **Command Rate:** — **50 Hertz**
- **Tracking error:** — **~1 arcsecond RMS both axes**

SLR2000 Tracking Mount

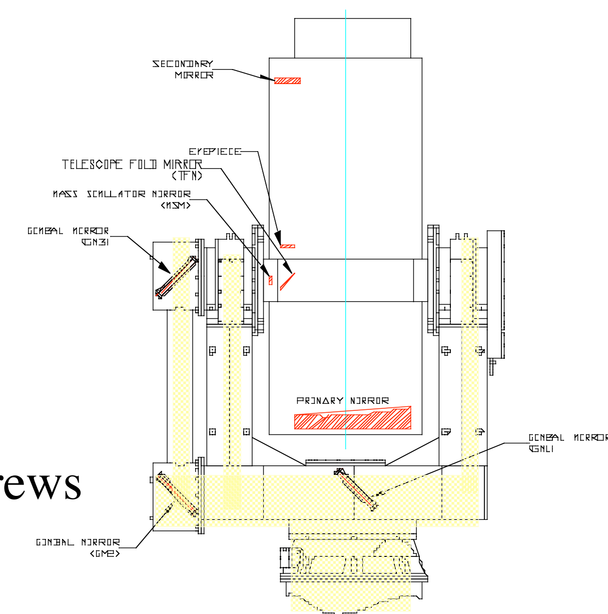
Problems Encountered

(at Zybion)

Late delivery

Pointing Accuracy

Tracking Stability



Solutions:

Work with Zybion to suggest solutions, Look up tables, Feed forward, motor cogging issues

Delivery to GSFC

Mount delivered with lose screws

Gimbal mirrors not aligned

Dog bone flexure problem

Limited access to adjustments

Align Gimbal mount, secure all fasteners, access port with cover fabricated, alignment optics & fixtures made

Lessons Learned:

Field Alignment is required, ergonomic access ports needed for adjustments. Goal: Factory assembled/aligned gimbal and telescope

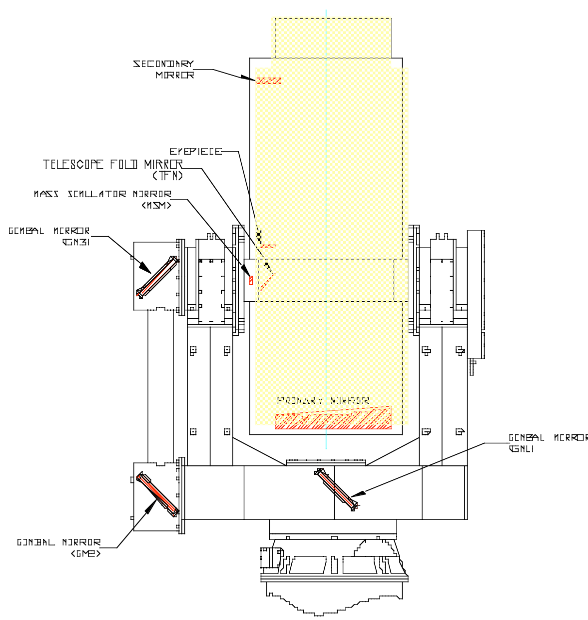
SLR2000 40cm Off-Axis Telescope

Problems Encountered

Poor image quality (~18 arcsec
Improper fold mirror position
Inadequate fold mirror adj
Drawing error in fold mirror

Unresolved Issues

Telescope not optimally aligne
Some astigmatism and coma
Improper field lens position
Access ports still lacking
Field alignment fixtures minimal.



Solutions: (returned to OSC)

Primary mirror moved in cell
Modification of fold mirror

Al mount reproduced in SS by NASA

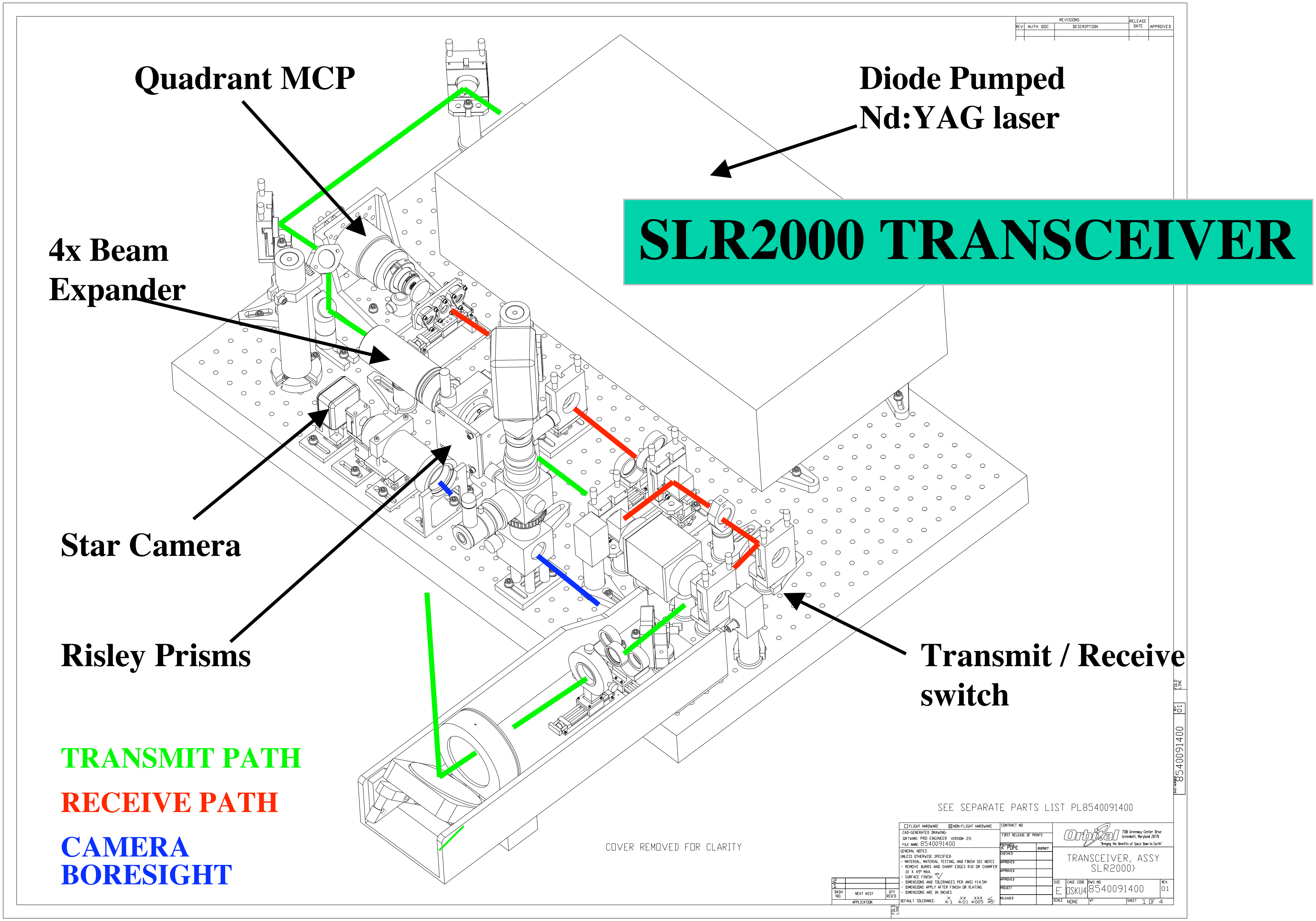
Proposed Solution:

At an appropriate time: Remove telescope and align in lab, install access ports, replace field lens, fabricate alignment fixtures

Lessons Learned:

Field alignment access ports required, or factory assembled/aligned gimbal and telescope suggested

SLR2000 TRANSCEIVER



SLR2000 Weather Instrument Suite

Overview of the Hardware

- Temperature, pressure and humidity measured with a Paroscientific model Met3
- Precipitation and visibility from a Vaisala model FD12P
- Wind speed and direction from a Belfort-Young model 05103
- Cloud map from a new IR instrument developed at NASA/GSFC
- All are interfaced via serial and analog cables to the SLR2000 Data Analysis Computer

SLR2000 Weather Station

Young 05103V
Wind Speed
Tracker & Monitor

Measures
- Wind Speed
- Wind Direction

Paroscientific MET3
Meteorological
Measurement System

Measures
- Pressure
- Temperature
- Humidity

TrueTime XL-DC
Time and Frequency Receiver
GPS Antenna
- Receives GPS Timing Information

Pelco MC3651H-2
Camera
- Remote System Monitoring
- System Security
- System Troubleshooting

All Sky
Camera
- Sky Visibility
- Cloud Cover

Vaisala FD12P
Weather Sensor

Measures
- Visibility
- Precipitation
- Precipitation Type
- Precipitation Rate

Current SLR2000 Status

➢Star Calibrations – working.

Star calibrations provide absolute pointing corrections for satellite tracking. Current 22 term trigonometric model was developed in-house.

- Star calibrations are now routinely taken in autonomous mode
-Stability of mount model appears good. The RMS of the starcal mount model is typically < 2.5 arcsec.

➢Ground Calibrations – working.

Ground calibrations provide a measure of the system delay which is needed to correct the roundtrip time of flight of satellites.

- Ranging data collected from the ground target with backup laser.
- Signal processing and automated search working with ground targets.
- Initial system delay calculated and used in satellite processing (RMS still high: 300 picoseconds)

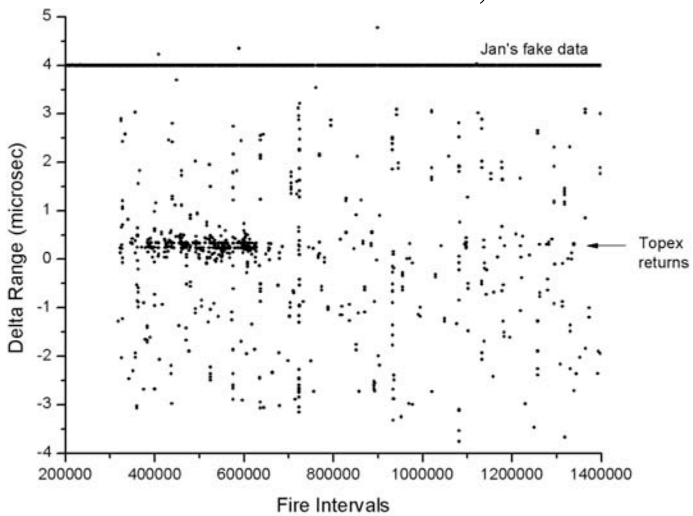
-Satellite Tracking – approximately 12 passes tracked.

Satellite tracking in SLR2000 is more complicated than in traditional SLR systems due to the high laser repetition rate, low return signal strength, narrow laser divergence and narrow field of view.

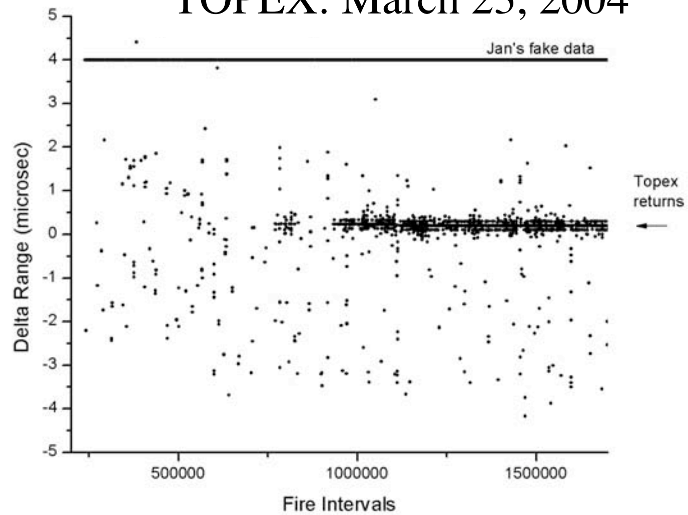
- TOPEX, AJISAI, and STARLETTE tracked (all LEO satellites). Several passes have been collocated with MOBLAS-7. Most passes were at night, but one AJISAI pass was taken around noon. SLR2000 data, with a 0.5 millisecond timebias applied, follows MOBLAS-7 data well.
- Signal processing and range bias calculation are working with satellite data.
- Mount is currently being pointed ahead of satellite (point-ahead).

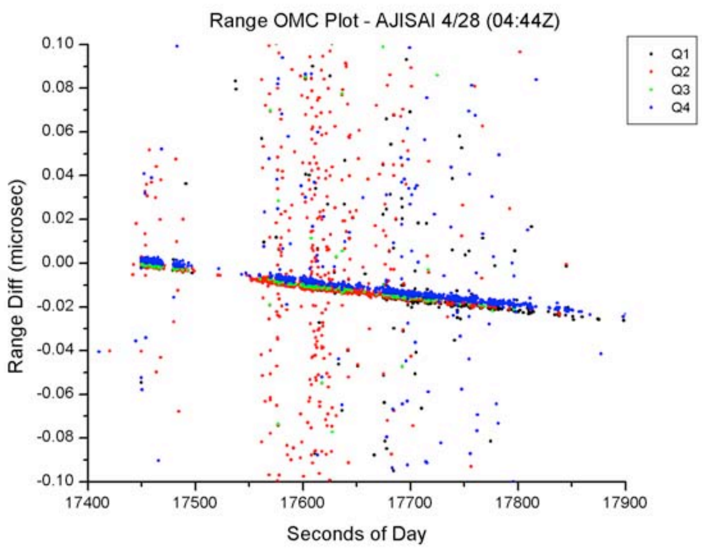
SLR2000 Satellite Tracks: OMC Plots

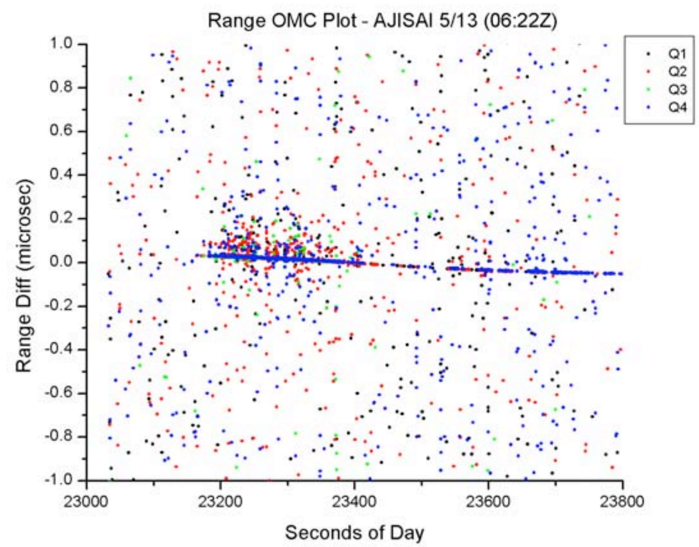
TOPEX: March 12, 2004



TOPEX: March 23, 2004







Technical Risks and Issues

- Adequate laser energy/lifetime not yet demonstrated
- Quadrant MCP photomultiplier tube lifetime unknown
- Closed loop quadrant tracking not yet demonstrated
- System automation/reliability testing a lengthy process
- Subsystem upgrade path needs consideration
- Prototype completion/success needed for risk mitigation
- TBD

SLR 5 - 10 Year Plan

Five year plan for replacement of SLR Network with SLR2000:

- Finish integration, testing and checkout of SLR2000 by CY 2004.
- Replicate, test and deploy 12 NASA SLR2000 systems globally over the next 5 years.
- Concurrent shutdown of existing manned NASA SLR systems.

Future plans and possibilities for SLR2000 Network:

- SLR2000 with the appropriate upgrades is a viable 2.4 Gb/channel LaserCom terminal for LEO to GEO platforms
- LaserCom downlink of data from Lunar Discovery or Mars is possible
- SLR2000/Lunar laser transponder considered for Lunar Reconnaissance Orbiter (LRO)